Phased Array Rotation Scanner Probe System for Ultrasonic Testing of Sleeve Shafts

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Abstract. The presented probe system combines several phased array probes for the ultrasonic testing of sleeve shafts of railway undercarriage axes to detect flaws with longitudinal and transverse orientation according to the set specifications. By employing acoustic beam steering, rotation and focus can be controlled electronically and factors such as the curvature of the borehole can be compensated for. The angular resolution of the rotation can be chosen freely and is independent of the number of array elements on the probe circumference.
On account of electronically steered rotation, inspection time decrease substantially and the manipulation system becomes simpler. Both attributes are desired, especially when the increasing number of inspections and resolution are considered that are required to increase technical safety and reduce costs.
The presuppositions to design and construct such probes are theoretical models to simulate the acoustic behaviour, especially the sound field pattern, dependent on the constructional parameters and steering conditions.

Introduction

The ultrasonic testing of the external surface of railway axes with a hollow drillings can be realized from the inside of the drill hole, without demounting the axes and without dismantling the wheels and the brake discs. Presently testing systems are used where scanning is realized in the circumferential direction by mechanical rotation of the probe system in the actual drilling. The phased array probe systems, which are presented here, can carry out the rotation scan electronically and they are qualified for different flaw orientations. The beam can be inclined exactly and be focused in the plane vertical to the specimen axis. Therefore manipulation becomes simpler and the inspection times can be shortened considerably.
Each probe consists of a rotation-symmetrical arrangement of phased array elements, designed according to simulation calculations, which generate a well-defined rotary sound field by suitable steering.

Setting of tasks

The testing system must be able to find flaws in the external surface of the hollow shafts whose surface lies in the radial-radial plane (now called transversal flaw) or in the axial-radial plane (now called longitudinal flaw). To achieve this objective different rotation scanner probes are required. A compact probe system can be designed to combine these rotation scanners. It is only necessary to move the system forward and backwards (non-rotary) inside the drilling and the whole scan can be carried out.

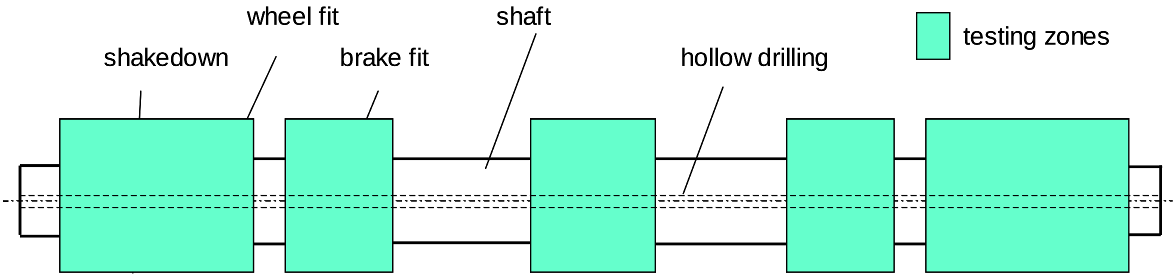

Fig. 1: example of a rail axis with bore hole and test zones

Functional principle of the rotation scanners

The phased array elements are positioned around the surface of a cylinder or a cone. A beam can be generated in a determined circular direction by using a number of elements lying side by side. These are summarized and create the active phased array. The sound field can be focused and the rotation angle can be exactly adjusted by a suitable steering. The coupling occurs using oil which is between the array and the inside surface. The influence of the rotation-symmetrical construction of the probe and of the refraction at the arched inside surface is compensated by the delay time allocation, so that the sound field shapes originate like they are usually used in the ultrasonic testing.

Some details about the conical probe

Extensive simulations were unavoidable to understand the acoustic behavior and to optimize the probe design to generate the most qualified sound field shape on account of the unusual geometry. The simulation model was developed at the BAM. The principle of the conical rotation scanner for angle beam testing of transversal flaws is shown in figure 2. The first results were already introduced in the year 2003 [1].

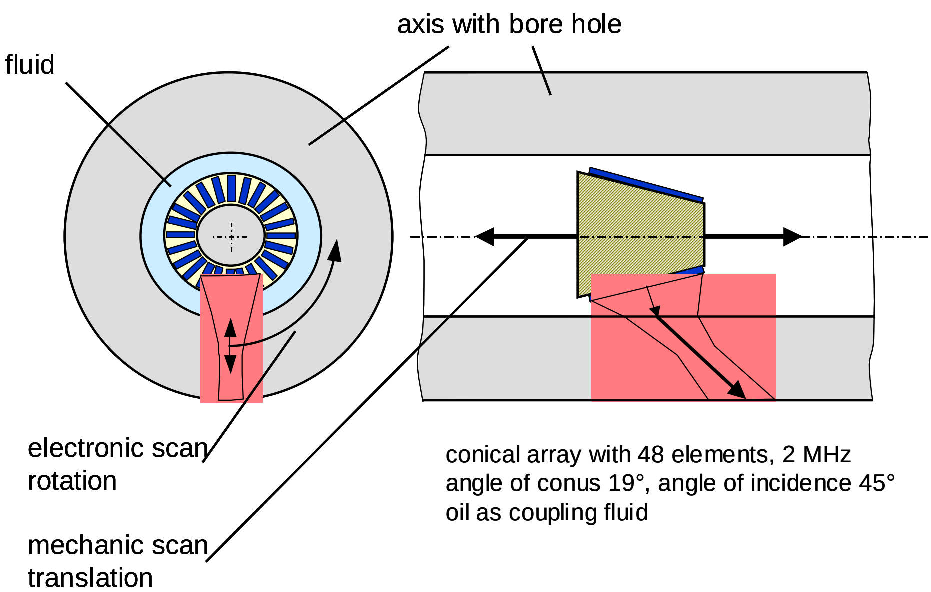

Fig. 2 conical rotation scanner phased array probe for indication of transversal flaws, principle

A test probe was built to test the functionality and whether the correspondence with the model calculations could be verified. Figure 3 shows the probe and the calculated sound field shapes in the plane of incidence and vertically thereto.

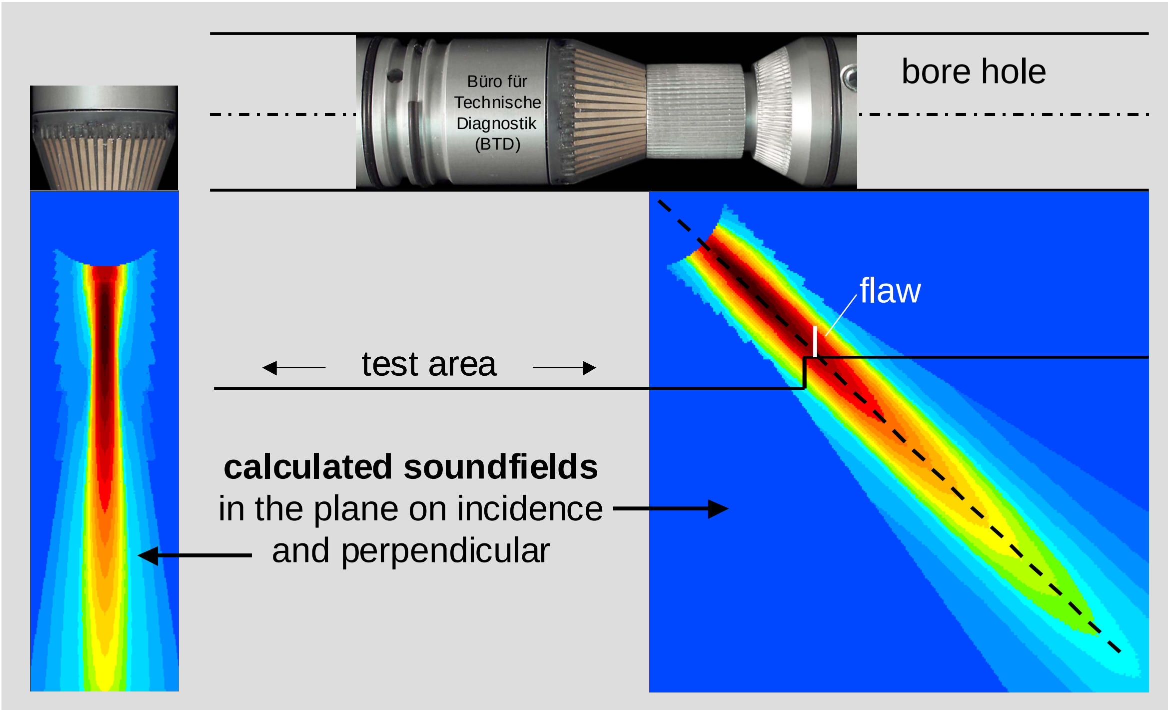

Fig. 3 conical rotation scanner phased array probe with calculated sound fields

The results of the measurements are completely in accordance with the simulated sound fields based on the calculated delay times. Figures 4 and 5 shows the echo indications of 2 mm deep notches in two test specimens with a 30 mm drilling diameter, however, with two different external diameters. With a mechanical adaptor (figure 6) the probe can also be employed in larger drillings. That was also confirmed experimentally.

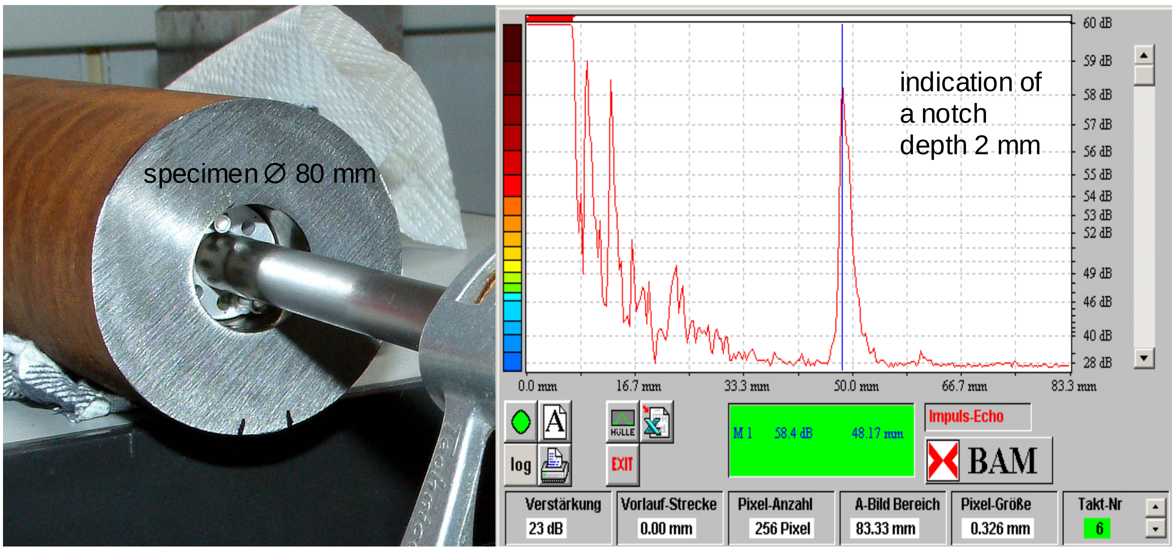

Fig. 4 conical phased array probe, indication of a notch

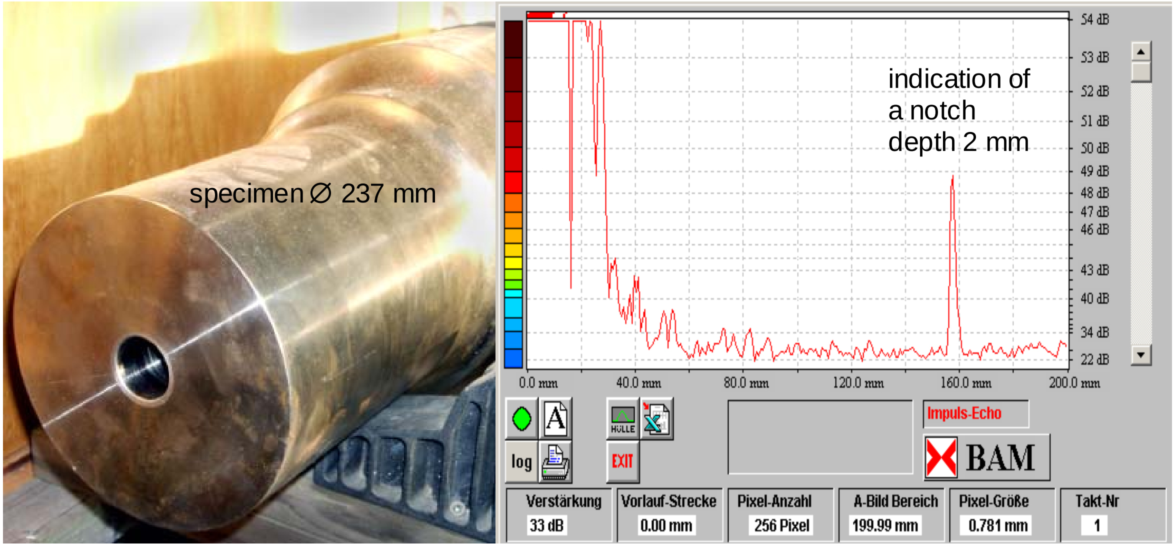

Fig 5 conical phased array probe, indication of a notch

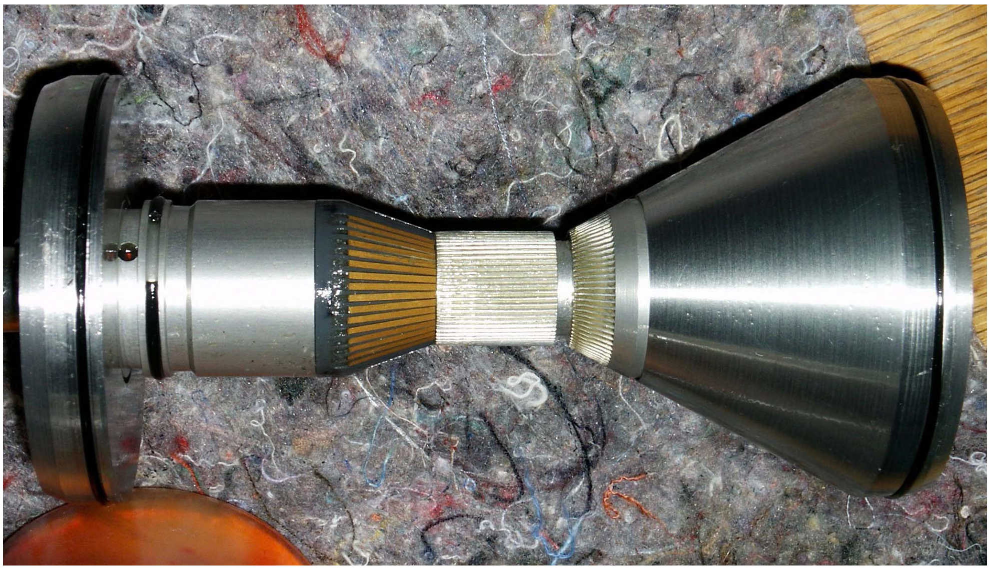

Fig 6 conical rotation scanner phased array probe adapted for bore hole Ø 70mm

How to detect longitudinal flaws

A longitudinal flaw can be detected from the inside of the drill hole, if the angle of impingement α_a illustrated in figure 7 is large enough to enable the use of the corner effect and if the direct reflection of the back wall does not exist. In addition, the echo height decreases with the angle α_a because the projection area of the flaw becomes smaller in the direction of the sound beam. The transducer must be turned by the angle δ (figure 7) in relation to the circumference position of the flaw, caused by the geometry and the refraction law.

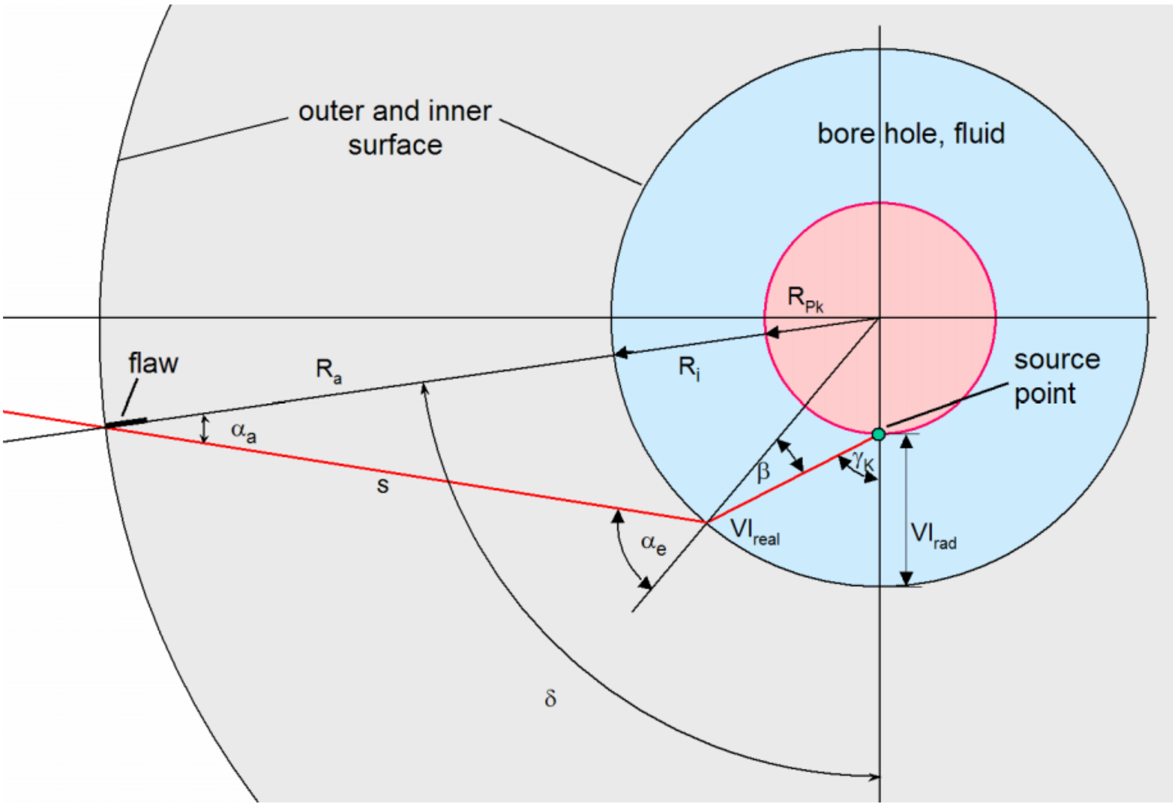

Fig 7 geometrical circumstances for the detection of longitudinal flaws out of the bore hole

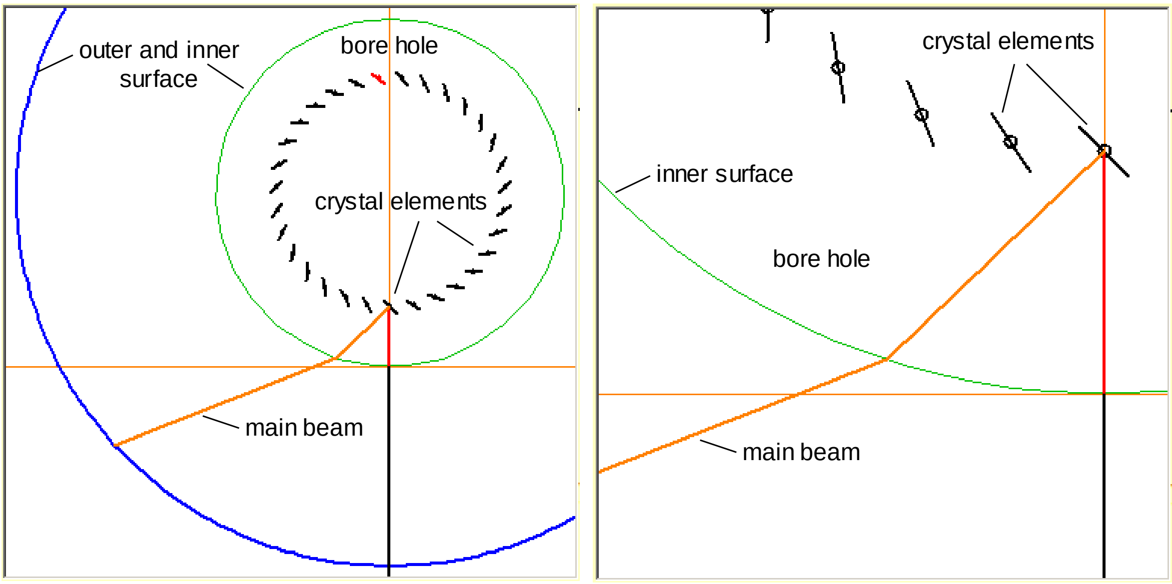

Fig 8 principle idea for the array probe for the detection of longitudinal flaws

Figure 8 shows the working principles behind the decisions on how the phased array elements in the rotation scanner array could be arranged. The calculations showed, that the adjustment of the elements in the direction of the main beam increases sound pressure substantially.

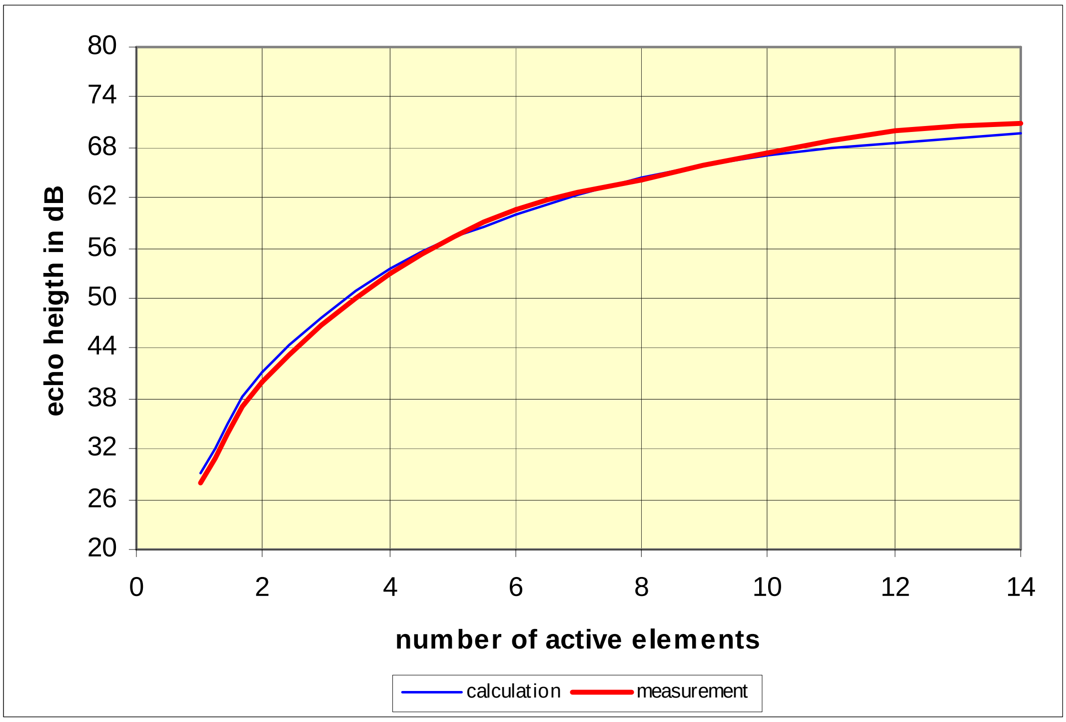

Fig 9 Echo height as a function of the number of active elements, calculated and measured

The echo height increases with the number of the active array elements (figure 9), but the edge elements supplies increasingly smaller contributions. The sound beam width is nearly the same in and vertically to the plane of incidence, if 10 array elements are active (cf. figure 10).

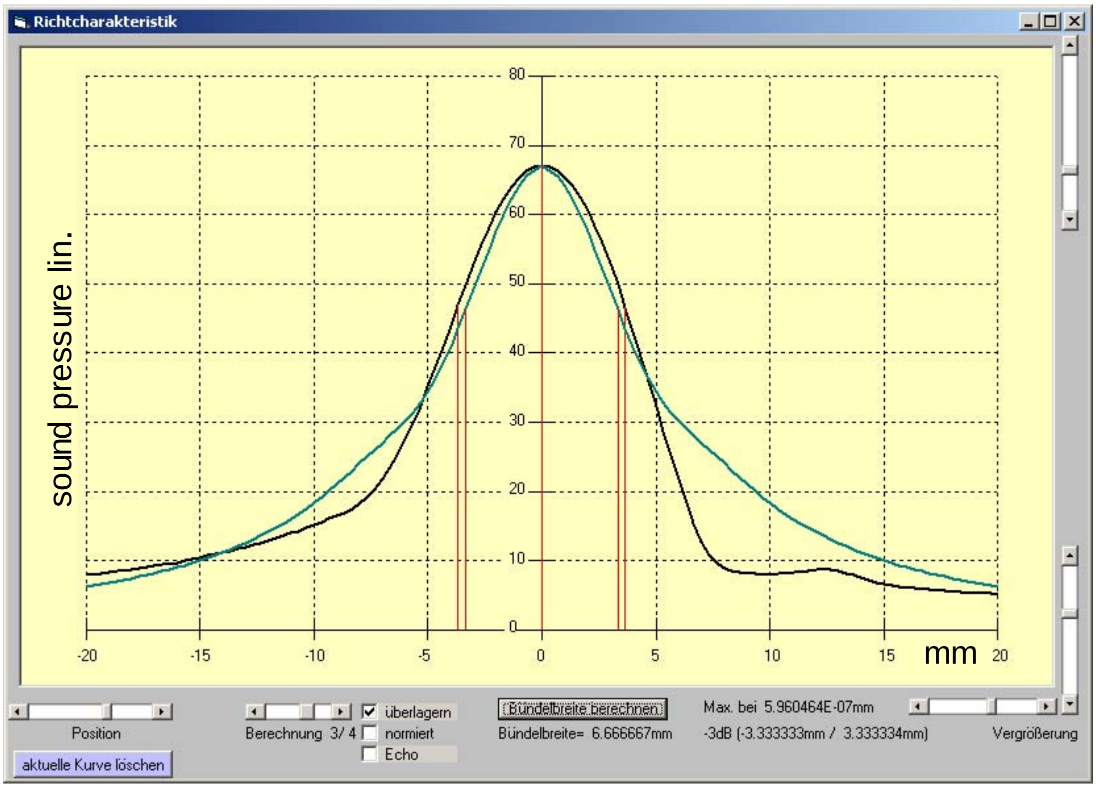

Fig 10 balanced beam width at the outer surface in the plane of incidence (black) and perpendicular to it (blue) using 10 active elements, sound path length 85 mm

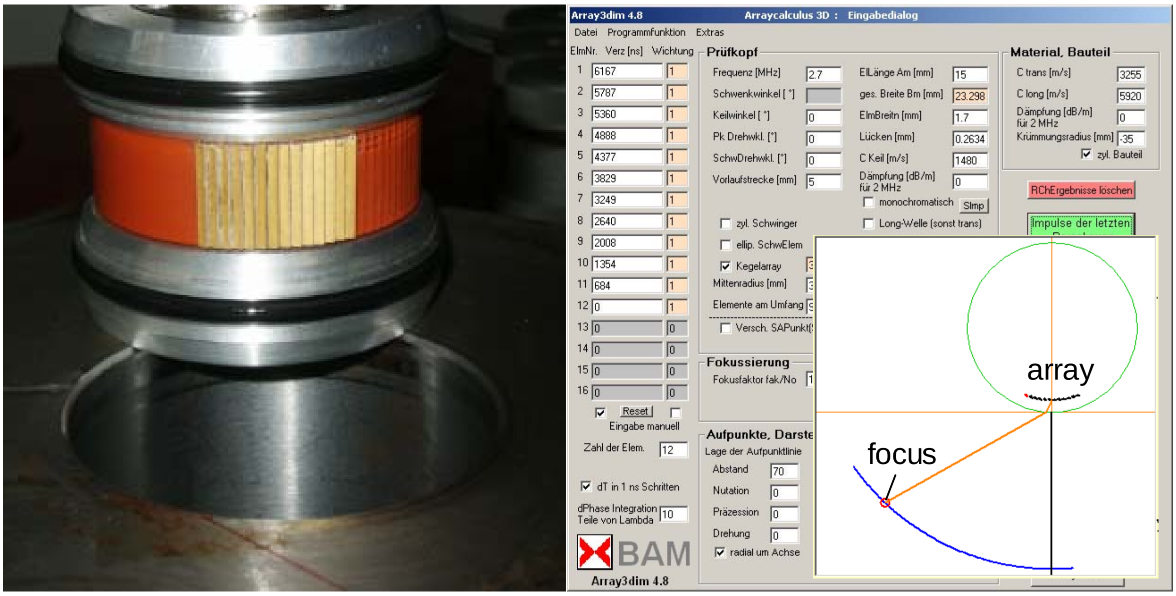

Fig. 11: test array with specimen (inner ∅ 70 mm, outer ∅ 200 mm), window of the parameters and the position of the geometrical focus

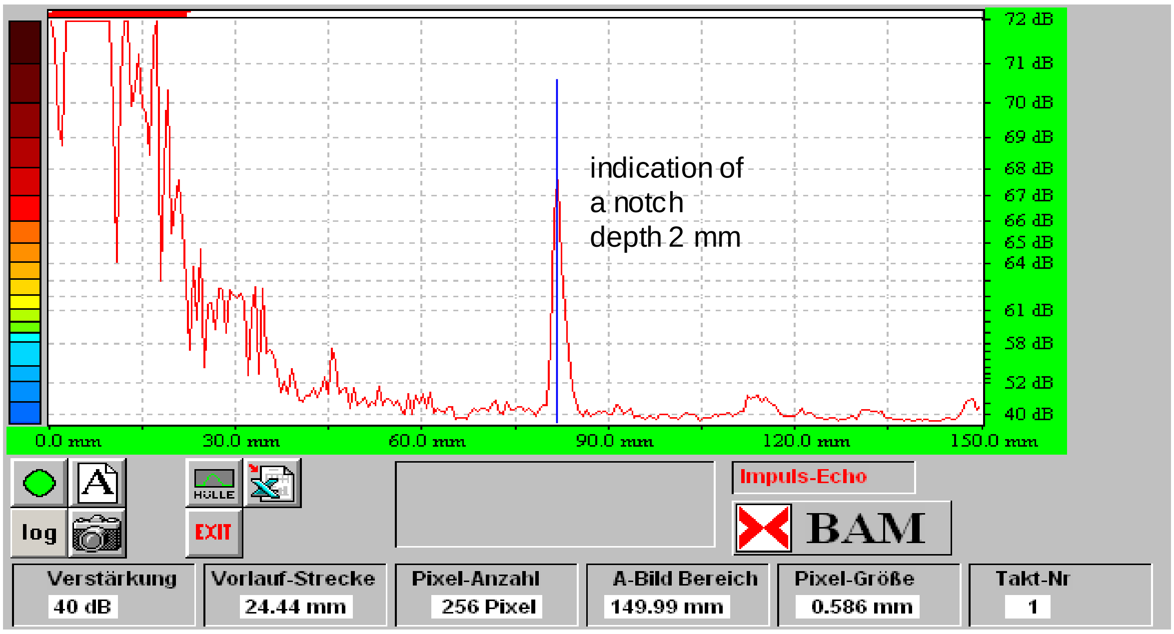

Fig. 12: echo signal from a 2 mm deep notch measured with the test array, 10 elements active

The measurements with the first probe proved the effectiveness and verified the simulated results. The echo signal has a S/N ratio better than 20 dB in the testing volume. The result is shown in figure 12. The spurious echoes with shorter sound paths are generated in the delay path and change only a little, if the probe is turned in the drilling. They could be suppressed by reference calculation, so that a good S/N ratio can be reached for sound paths greater than 30 mm.

Compact probe system for the complete testing of rail axis

The complete probe system for the testing of hollow-bored axes could look similar to the CAD model shown in figure 13. It contains rotation scanner probes for testing for longitudinal flaws and for transversal flaws with angles of incidence of 45° and 70° in the second case. The rotation scanners exist twice to be able to test flaws from both possible directions. The system is pushed into the drilling and is pulled out again (translation only) during the scan process. The costs could be reduced for the equipment (the probe and the phased array device), if the rotation scanners are covered only half-sided with array elements, so that the first half of the circumference is scanned while pushing the system in the drilling and the other half while pulling it out. Therefore the probe system in the drilling has to be rotated by 180°. The scanning time would be barely extended thereby.

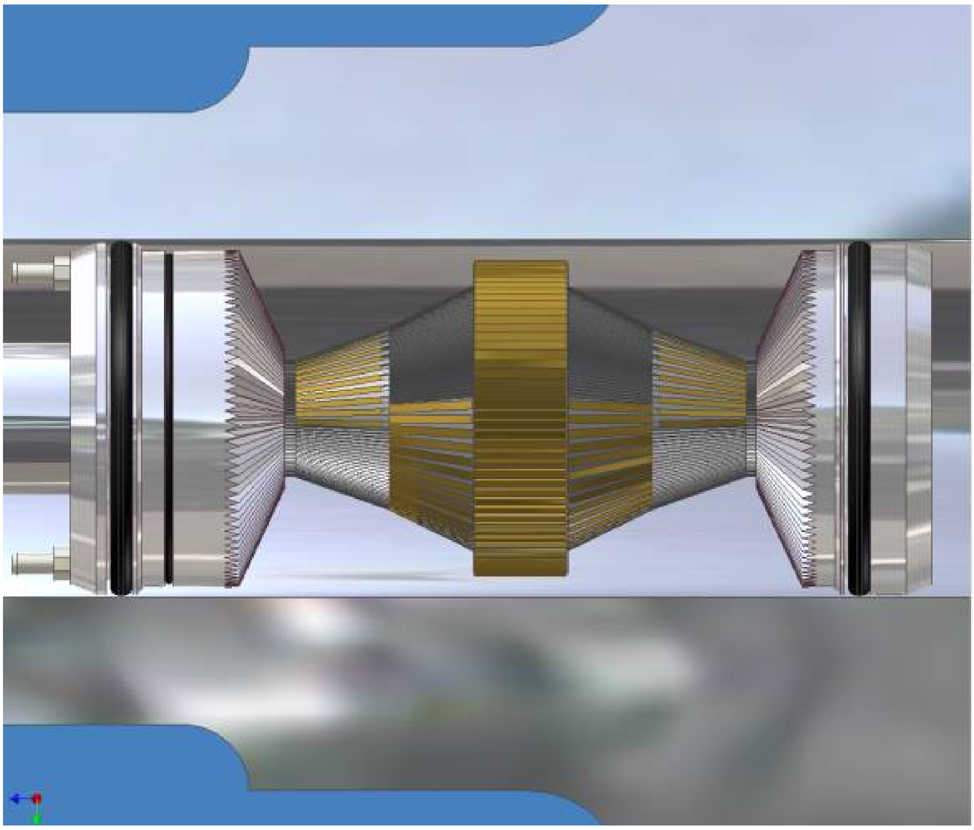

Fig. 13: compact probe system for the complete test of rail axis with a bore hole of 70 mm diameter

Conclusion

A rotation scanner phased array system was developed to test hollow-bored railway axes with ultrasound, without mechanical rotation of the probe system to simplify the manipulation system. The rotation scanners were constructed on the basis of simulation calculations and their effectiveness as well as their sensitivity with a good signal to noise ratio were verified experimentally. The scan time using this system to test one shaft would take roughly 2 minutes. That is significantly faster than comparable mechanically rotated probe systems.

References

[1] R. Boehm, A. Erhard, T. Rehfeldt, Einfluss fokussierter Schallfelder auf das Reflexionsverhalten von Testfehlern, DGZfP-Jahrestagung 2003 in Mainz